
Protons on Target

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MI/Beams

Goals

- Double the beam intensity on the antiproton production target (from $4E12$ to $8E12$).
- Limit the length of the stacking cycles to 2 sec (including 5 Booster batches for NUMI).
- Produce a bunch length on pbar target smaller than 1.5 nsec.
- Limit the transverse emittances of the beam on target to 25 π -mm-mrad or less.
- Upgrade the antiproton production target to take full advantage of the increased proton intensity.
- All the above are expected to increase the current stacking rate by a factor of 2.0 (from present).

WBS Summary

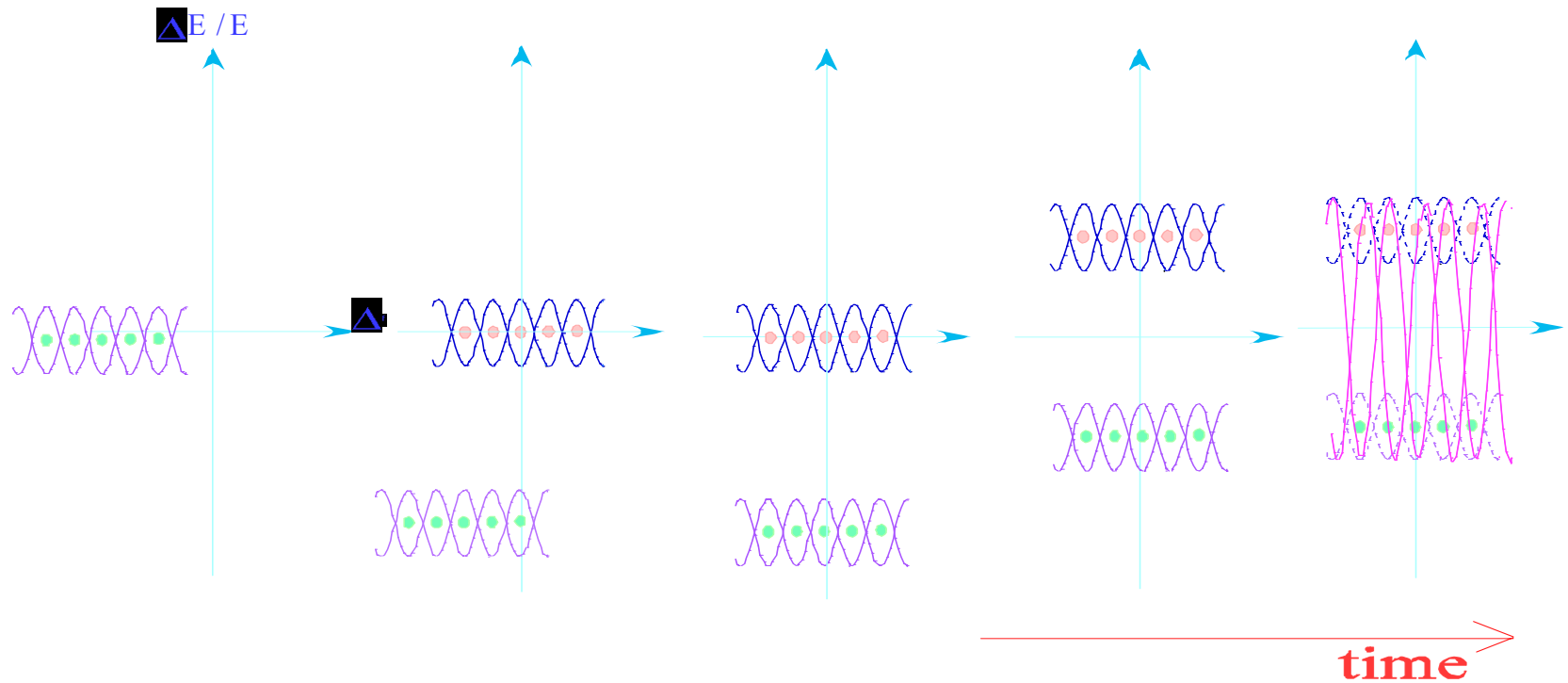
| WBS | Subproject | In Charge | Finish Date | M&S Est | M&S Cont |
|-----------|--------------------------|----------------|-------------|----------------|----------|
| 1.3.1 | Protons on Pbar Target | I.Kourbanis | 2/7/05 | \$1,671,500.00 | 38% |
| 1.3.1.1 | Slip Stacking | R. Pasquinelli | 12/14/04 | \$650,000.00 | 35% |
| 1.3.1.2 | Pbar Target and Sweeping | J. Morgan | 3/01/04 | \$96,500.00 | 38% |
| 1.3.1.2.1 | Target | J. Morgan | 12/30/03 | \$20,000.00 | 20% |
| 1.3.1.2.1 | Beam Sweeping system | J. Morgan | 3/1/04 | \$76,500.00 | 42% |
| 1.3.1.3 | MI Upgrades | I. Kourbanis | 2/7/05 | \$925,000.00 | 41% |
| 1.3.1.3.1 | MI Dampers | B. Foster | 3/22/04 | \$0.00 | |
| 1.3.1.3.2 | MI BPM Systems | B. Choudhary | 10/6/04 | \$900,000.00 | 40% |
| 1.3.1.3.3 | MI 2.5 MHz Acc. | C.Bhat | 2/7/05 | \$25,000.00 | 60% |

Protons on Target, I. Kourbanis

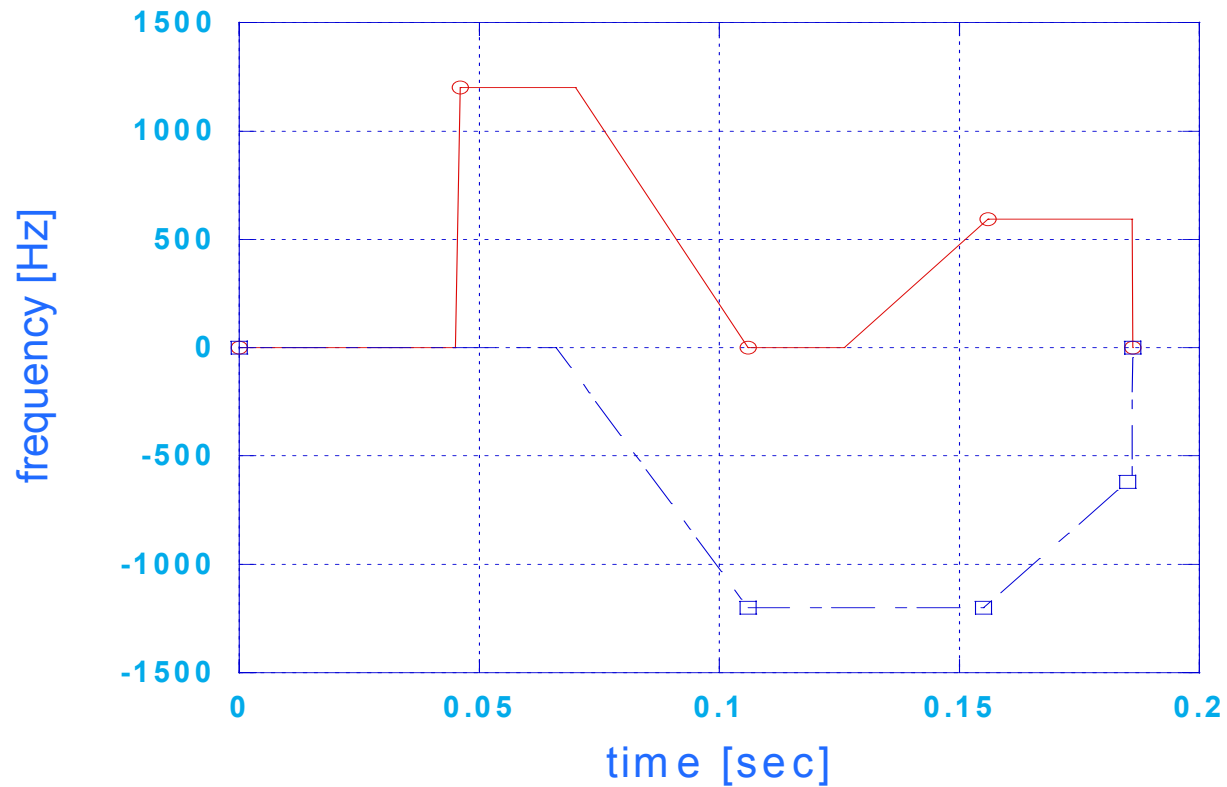
Slip Stacking

- Slip stacking has been demonstrated successfully at low intensities ($1.0E12p$) in the Main Injector.
- The slip-stacking efficiency was 98% and the final longitudinal emittance blow-up was a factor of 1.6 in agreement with the simulations.
- No longitudinal emittance blow-up has been observed during the slipping of the two batches.
- Most of the LLRF tools needed for slip stacking have been developed.
- The whole slip stacking process is completed in less than 0.133 sec (two Booster ticks).

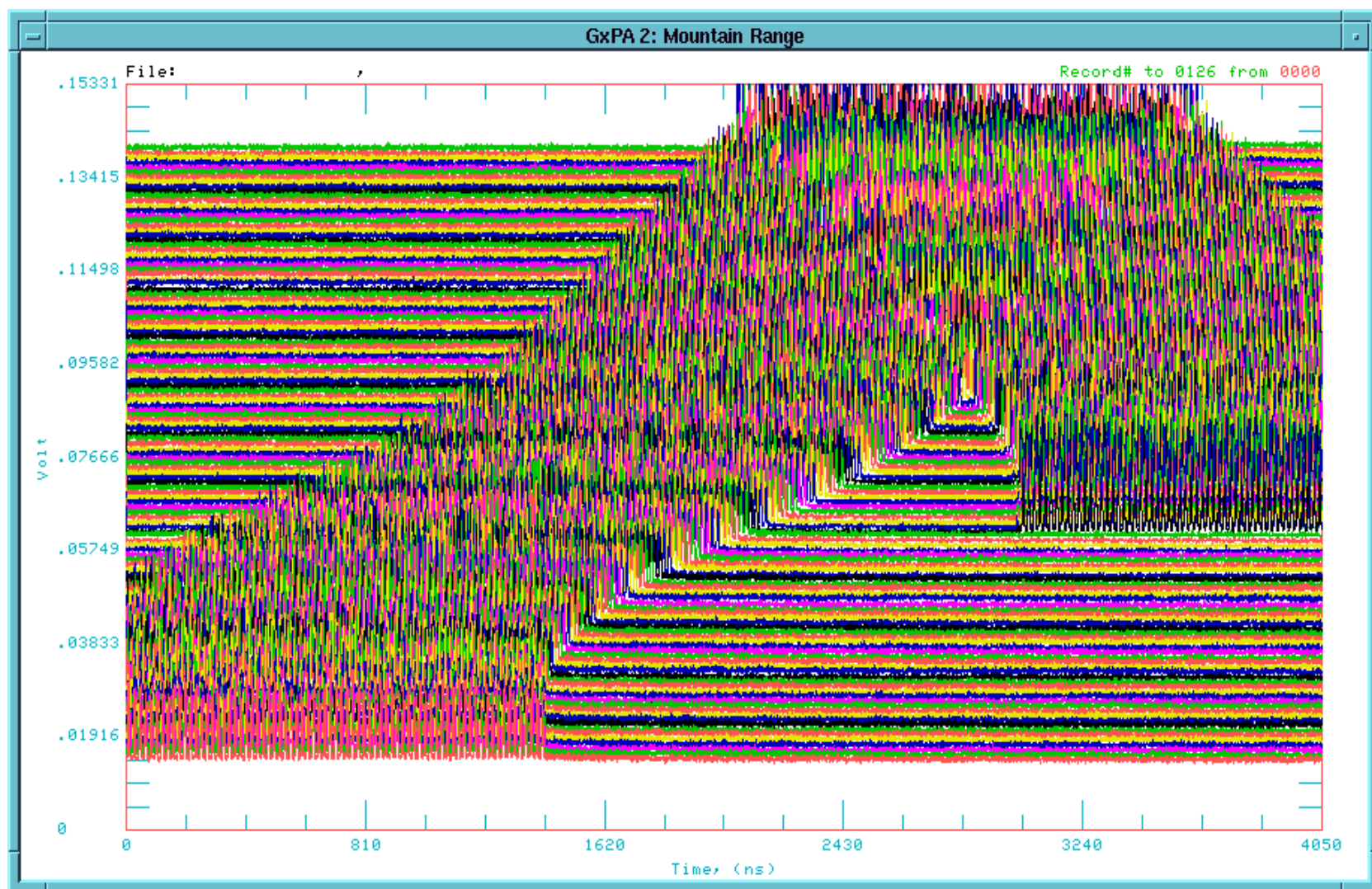
Slip Stacking cartoon



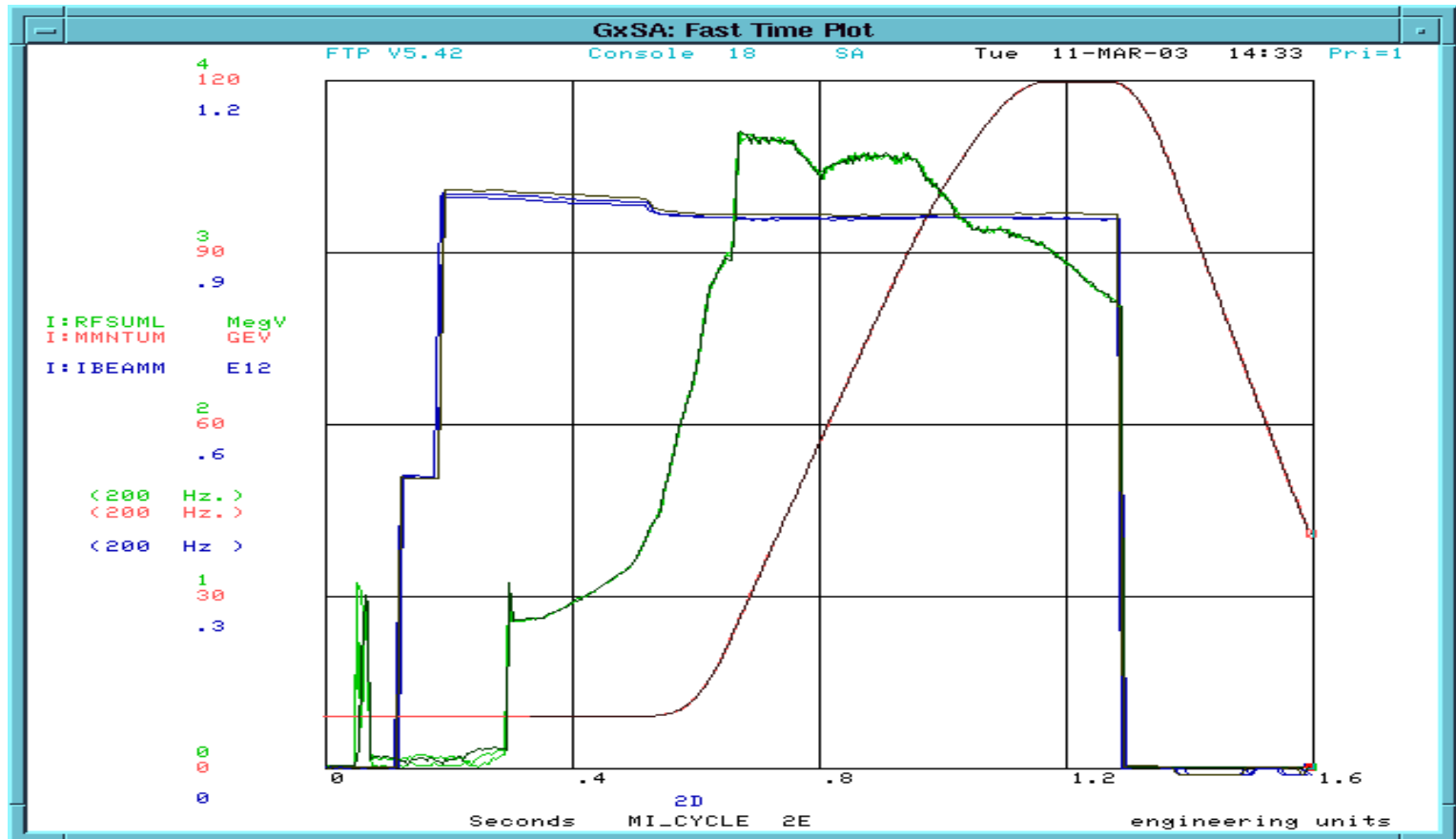
Slip Stacking Frequency Curves



Slip Stacking Mountain Range Plot with 1E12p



Acceleration to 120 GeV after slip stacking



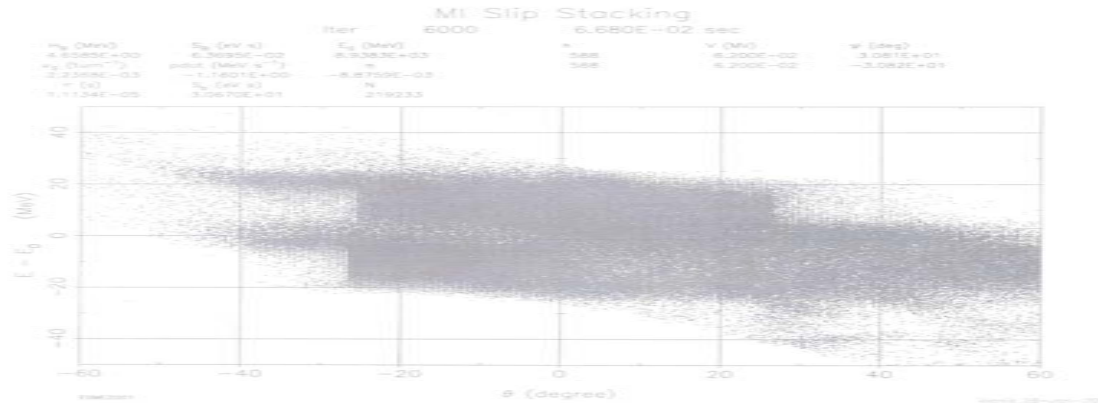
Beam Loading Compensation

- Beam loading on the 53 MHz accelerating cavities is the biggest problem during slip stacking.
- From ESME simulations is determined that at least a factor of 20 (26 db) reduction of the beam loading voltage is required.
- We can achieve the beam loading compensation using a combination of feed-forward and feed-back.
- We are using a tube performance calculator in Matlab to analyze the performance of the Eimac Y567 cavity tetrodes tubes.
- We have developed a Matlab Simulink model to help us analyze the dynamic behavior of a single MI RF cavity with its control loops and beam-loading compensation loops. The cavity response to a triangular beam pulse is used as an input to the ESME simulation program.

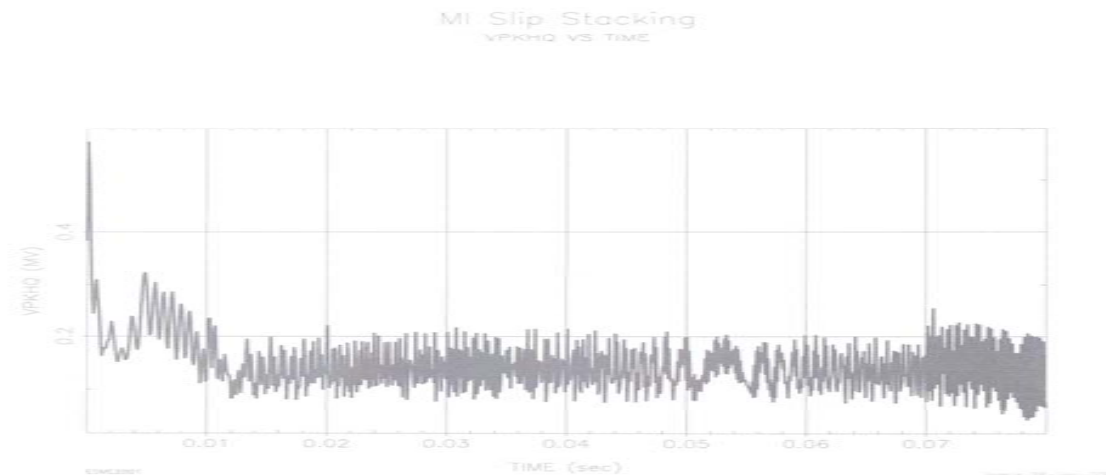
Beam Loading Compensation (2)

- We are currently applying feed-forward compensation with a gain of 20-25db during both proton and pbar coalescing (total beam intensities of $4E11$ or less).
- By changing the operation point of the final tube from class AB to class A in one rf station we were able we were able to achieve a total feed-forward compensation of 22 db (a factor of 12.6 reduction) during injection on the stacking cycles with total intensity of $4.5E12$ ppp.
- We have determined that currently we have enough rf current available to supply the beam-loading compensation required for slip stacking up to intensities of $8E12$ ppp.
- Additional solid state amplifier modules will be needed in order slip stacking to become operational.
- We are currently working on applying feed-forward beam loading compensation during slip stacking with most of the rf stations off(no rf drive).

ESME Simulations of slip stacking with 1E13p and no Beam Loading Compensation

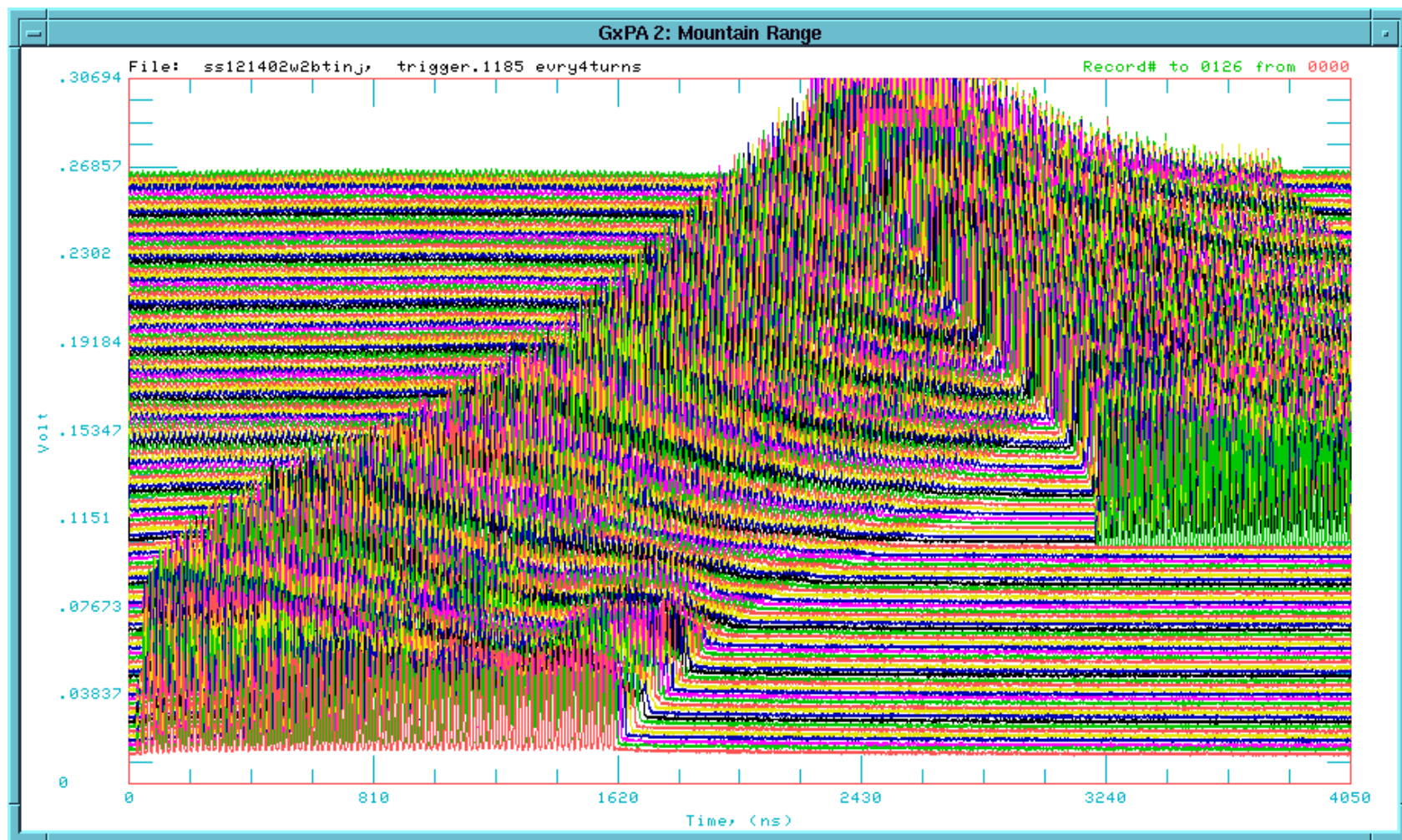


Phase space plot

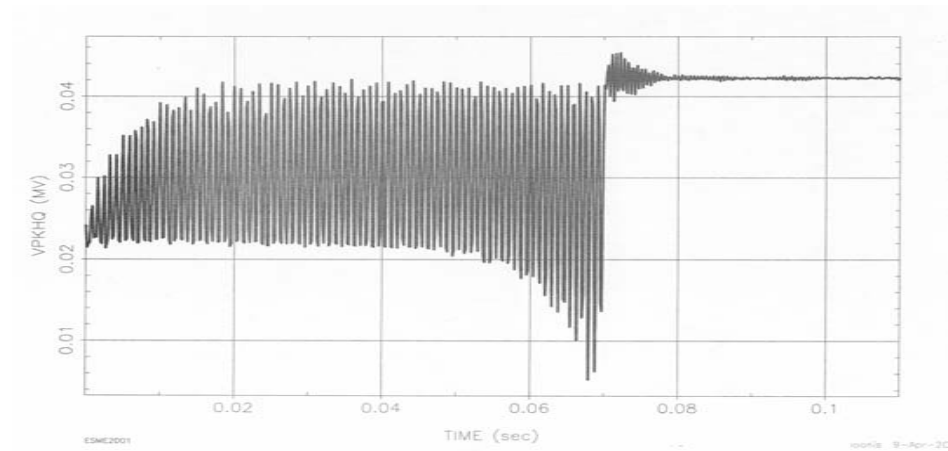
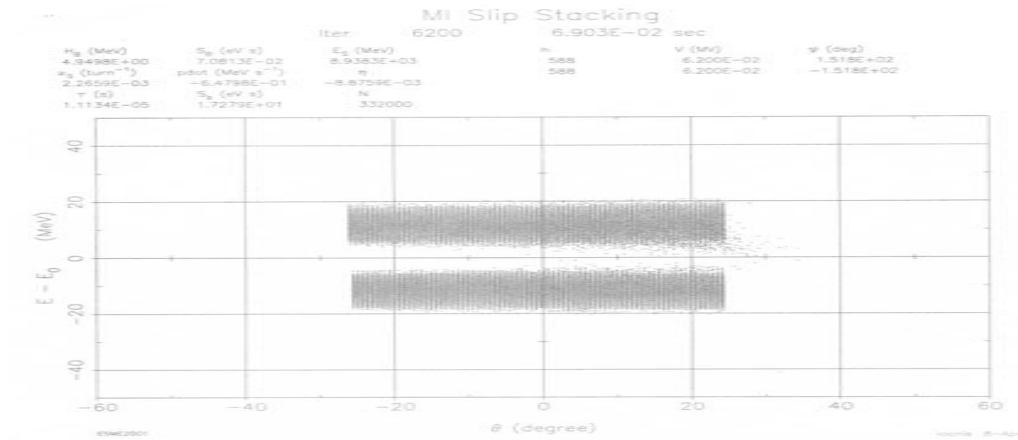


Beam induced voltage

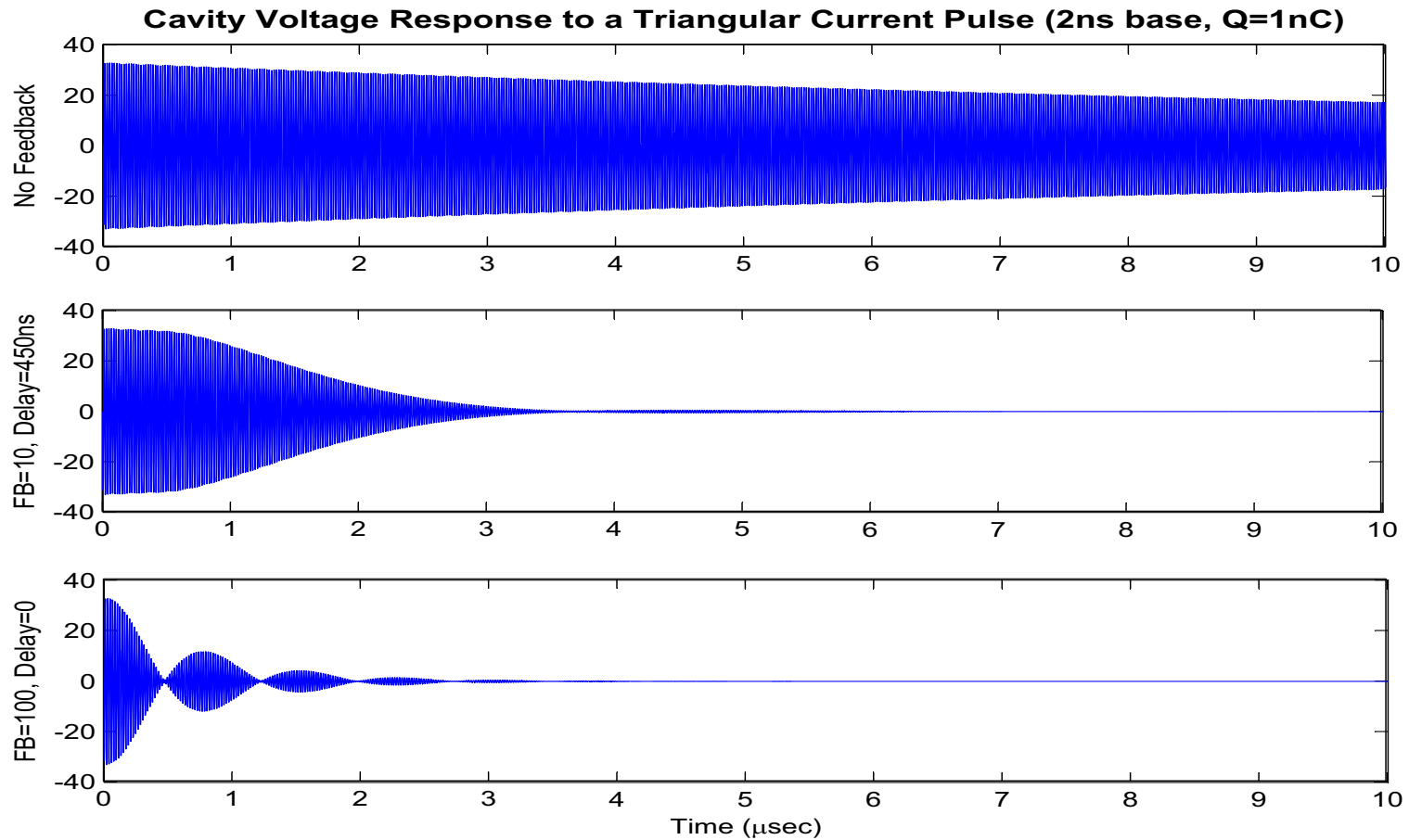
Slip Stacking mountain range with $4.5E12p$ and no BLC



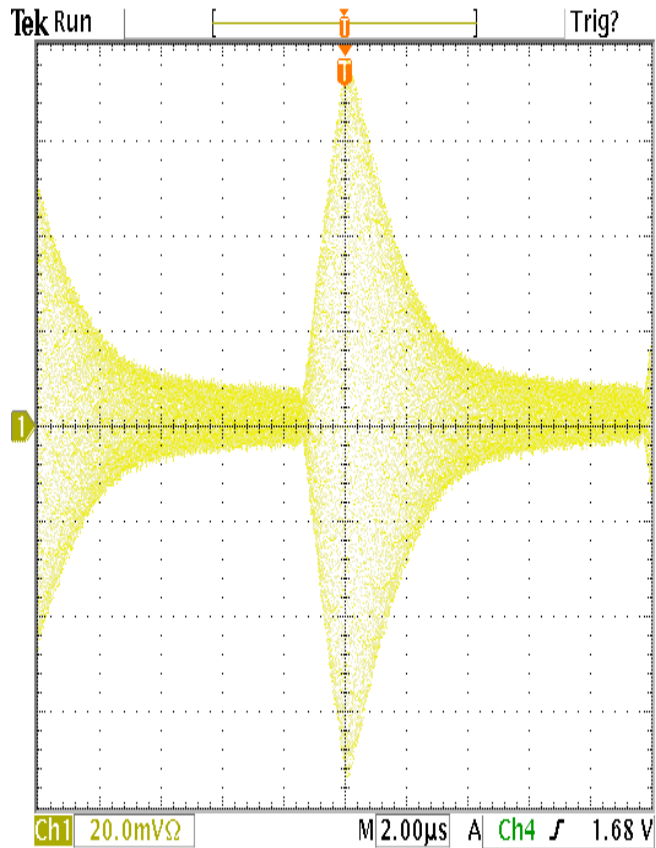
ESME Simulations of slip stacking with 1E13p 20db of feed-forward and 14db of fundamental feedback.



Simulated cavity voltage response to a triangular current pulse for various system conditions.

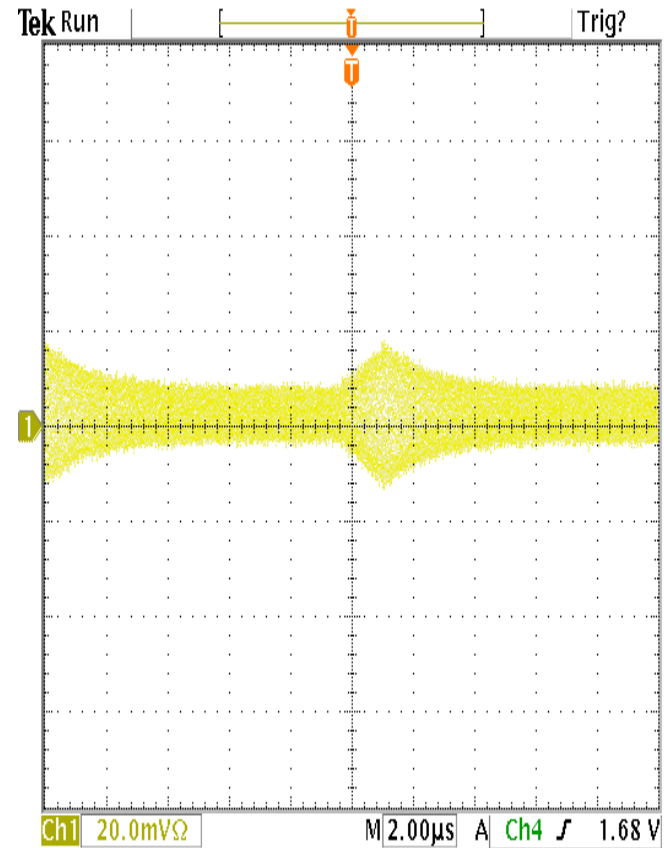


Beam Induced voltage on one rf station with no rf drive



24 Jun 2003
17:29:18

Feed-forward compensation OFF



24 Jun 2003
17:29:56

Feed-forward compensation ON

Other Beam Dynamics Issues

- **Booster bunch rotations**
 - Beam in the Booster has to be rotated in the longitudinal phase space before extraction in order to match the low voltage (62KV) buckets in MI
 - Booster longitudinal mode dampers have to work at the highest intensities
- **Transition crossing in MI**
 - Transition crossing in MI is expected to blow-up the longitudinal emittance of the bunches by 30-35%.
- **Longitudinal Instabilities**
 - Couple bunch instabilities can dilute the longitudinal emittance of the bunches and affect the bunch rotation at 120 GeV needed to reduce the final bunch length at the target.
 - A bunch by bunch longitudinal damper is expected to be operational by the end of this year.
- **Transverse instabilities**
 - Bunch by bunch horizontal and vertical dampers are being commissioned.

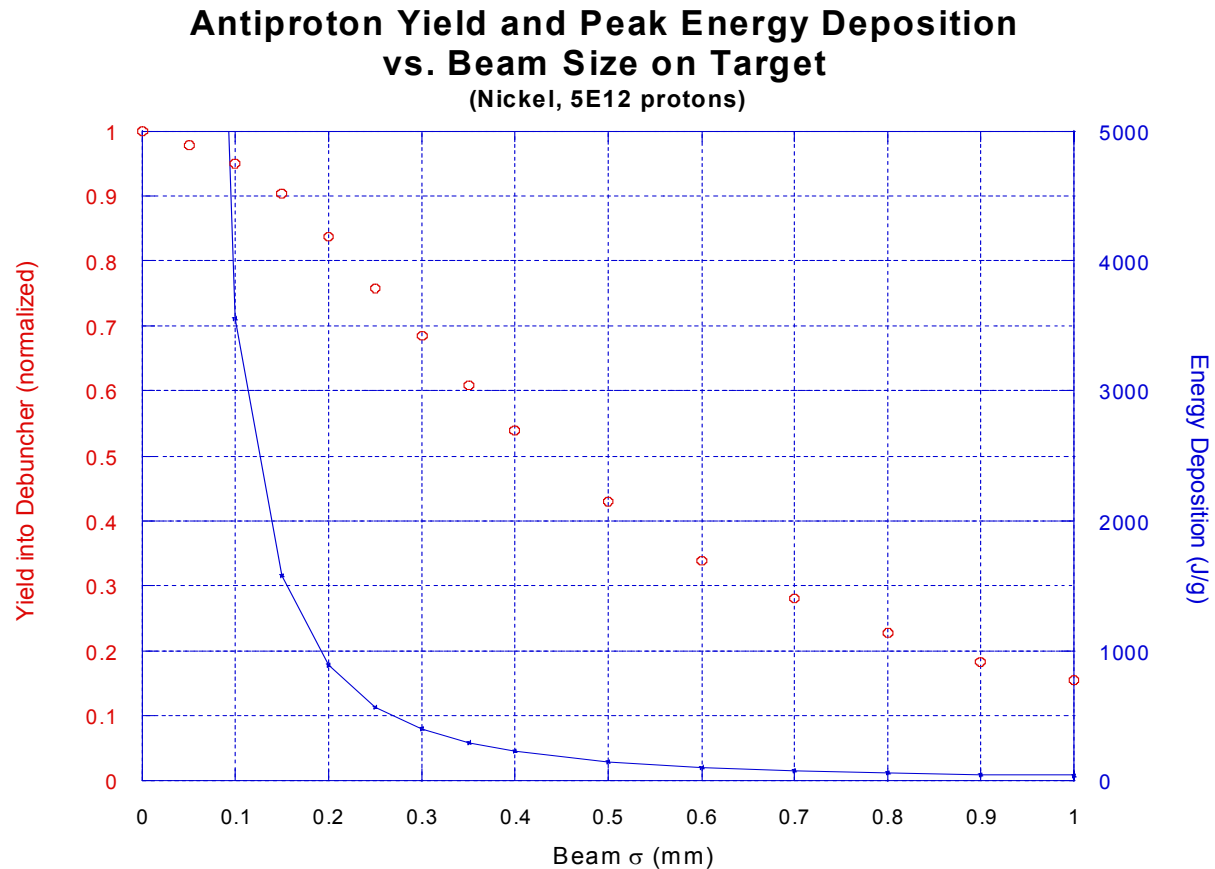
Pbar Target Energy Deposition and Beam Sweeping

- The antiproton production target should be able to take full advantage of the increased proton intensity.
 - No reduction in antiproton yield.
 - Prevent local melting and target damage.
 - Maintain a beam spot size at the target of 0.1mm with larger transverse emittances.
- New target materials with same yield characteristics as the present target but better tolerances have been investigated.
- A beam sweeping system that moves the targeted beam during the 1.6 μsec beam pulse has been constructed.
- Plan to develop beam-line lattice changes that will reduce the beta functions at the target so that $\sigma=0.1$ mm in both planes with proton emittances up to 25 $\pi\text{-mm-mrad}$.

Pbar Target Energy Deposition and Beam Sweeping (2)

- Inconel 600, 625, 686, X-750 and Stainless Steel 304 have been tested with beam and compared with Nickel 200. Based on the yield characteristics and resistance to damage Inconel 600 has been identified as the operational target material.
- The upstream target sweeping magnets have been installed in the tunnel and are ready to be tested. The downstream sweeping magnet is being completed and expected to be installed when the testing of the upstream magnets is finished.
- Recent beamline optics improvements have zeroed the dispersion at the target and reduced the spot size to $\sigma_x=0.15\text{mm}$ and $\sigma_y=0.16\text{mm}$ with transverse emittances of 19 pi-mm-mr.
- To achieve the goal of $\sigma_x = \sigma_y = 0.1 \text{ mm}$ with a 25 pi-mm-mrad beam the beta functions at the target will need to be reduced an additional factor of two. New optics solutions will be modeled and tested with beam during the second half of 2003 to identify possible aperture problems.

Antiproton Yield and Peak Energy Deposition vs. Beam Size on Target (from MARS model)



Target Reduction yield studies for different materials

| Material | Spot size | Starting Yield | Ending Yield | Protons on target | Yield reduction scaled to 10^{18} protons |
|----------------------------|----------------------------|----------------|--------------|-----------------------|---|
| Nickel 200 | $\sigma_{xy} = 0.15, 0.16$ | 1.000 | 0.970 | 5.7×10^{17} | 5.3% |
| Nickel 200 | $\sigma_{xy} = 0.22, 0.16$ | 0.990 | 0.935 | 6.6×10^{17} | 8.3% |
| Inconel [®] 600 | $\sigma_{xy} = 0.15, 0.16$ | 0.995 | 0.970 | 10.6×10^{17} | 2.4% |
| Inconel [®] 600 | $\sigma_{xy} = 0.22, 0.16$ | 0.990 | 0.960 | 10.7×10^{17} | 2.8% |
| Inconel [®] 625 | $\sigma_{xy} = 0.22, 0.16$ | 0.980 | 0.970 | 6.6×10^{17} | 1.5% |
| Inconel [®] X-750 | $\sigma_{xy} = 0.15, 0.16$ | 0.985 | 0.965 | 5.7×10^{17} | 3.5% |
| Inconel [®] 686 | $\sigma_{xy} = 0.15, 0.16$ | 0.970 | 0.935 | 1.0×10^{17} | 38.2% |
| Stainless 304 | $\sigma_{xy} = 0.15, 0.16$ | 1.000 | 0.965 | 6.1×10^{17} | 5.8% |

Milestones

| WBS | Subproject/Milestone | MS Class | MS Date |
|---------------|--|----------|----------|
| 1.3.1 | Protons on Pbar Target | | |
| 1.3.1.1 | Slip Stacking | | |
| 1.3.1.1.6 | Design Review (Milestone) | C | 9/22/03 |
| 1.3.1.1.10 | Start Slip Stacking Assembly (Milestone) | C | 2/9/04 |
| 1.3.1.1.13 | Slip Stacking Operational (Milestone) | A | 12/14/04 |
| 1.3.1.2 | Pbar Target and Sweeping | | |
| 1.3.1.2.1 | Target | | |
| 1.3.1.2.1.4.3 | New Target in Operation (Milestone) | A | 12/30/03 |
| 1.3.1.2.2 | Beam Sweeping system | | |
| 1.3.1.2.2.4.2 | Beam Sweeping Operational (Milestone) | A | 1/21/04 |
| 1.3.1.3 | MI Upgrades | | |
| 1.3.1.3.1 | MI Dampers | | |
| 1.3.1.3.2 | MI BPM Systems | | |
| 1.3.1.3.2.3 | MI BPM: Review (Milestone) | C | 2/3/04 |
| 1.3.1.3.3 | MI 2.5 MHz Acceleration | | |
| 1.3.1.3.3.2 | Review MI 2.5 MHz Acceleration (Milestone) | C | 8/1/03 |

Conclusions

- ❑ Most of the tools required for slip stacking have been developed and the process has been demonstrated to work as expected at low beam currents.
- ❑ A serious effort is under way in order to understand what is needed to compensate the beam loading in the 53 MHz cavities at large currents.
- ❑ Both transverse and longitudinal dampers will be needed during the slip stacking cycles.
- ❑ We have identified a new target for antiproton production.
- ❑ Beam sweeping magnets are ready for testing with beam.